

RESEARCH PROJECT YEAR-END REPORT
THE INSTITUTE OF GEOPHYSICS AND PLANETARY PHYSICS
LOS ALAMOS NATIONAL LABORATORY

Title: Measuring and Modeling Fluid Movements in Volcanoes: Insights from Continuous Broadband Seismic Monitoring at Galeras Volcano, Colombia
IGPP Award Number: 1407

By Margaret Hellweg, Douglas Dreger & Leigh House

Objectives

High-quality seismic recordings from two different volcanic environments are to be analyzed to investigate the underlying mechanisms of the seismic events, and learn about their relations to movement of fluids in volcanic systems. This analysis will focus on the frequency peaks in the seismic data, and will also include other signal characteristics. These data will be used to develop and expand fluid dynamical models for the source of the seismic events, as well as attributes of the fluid/magma transport within the volcanoes. These results may help identify the dynamic processes that lead up to an eruptive outbreak.

Summary of Workplan for FY05

1. Tasks: Based on the results of the measurements on tornillos, we will continue to investigate and refine possible theoretical and numerical source models (Hellweg, 2000b, Seidl and Hellweg, 2004). We will begin analysis work on seismic events from the Valles Caldera, to search for similar tornillo-style seismic events and determine their signal characteristics in a similar way to Galeras' tornillos. As the development of models progresses, we will examine which volumes of parameter space from the tornillo source models might explain the Valles events, and what implications that has for hazard assessment and monitoring.

2. Milestones:

In the second year, we will characterize events from Valles Caldera using the methods and insights from the investigation of Galeras' tornillos. We will complete the development of theoretical and numerical source models for tornillos and examine different volumes of parameter space in terms of possible physical source processes, and their predictions for relationships between event types and changes in volcanic activity.

3. Deliverables: During the second year, at least one paper describing our results will be submitted to a peer-reviewed journal. In addition, we expect to present results at professional meetings to report on progress and conclusions. The research team will also present results in talks at both the Berkeley and the Los Alamos campuses.

Statement of research results to date

During the past year we collected and analyzed data for tornillo events from Galeras Volcano, Colombia. Such events were associated with eruptions in 1992-1993. The initial dataset consisted of

almost 90 tornillo events recorded by the broadband seismic station ANG beginning with the swarm in 12/1999-2/2000. The dataset includes events up to the end of 2002, the last tornillos to be recorded before the reinitiation of eruptive activity in July 2004. The tornillos have between 1 and 15 spectral peaks (Figure 1). While examining the tornillos during analysis, we learned that each tornillo waveform can actually be divided into three parts, that can be seen best in tornillos which have a high signal-to-noise ratio (Figure 2). On records from shortperiod seismographs with limited dynamic

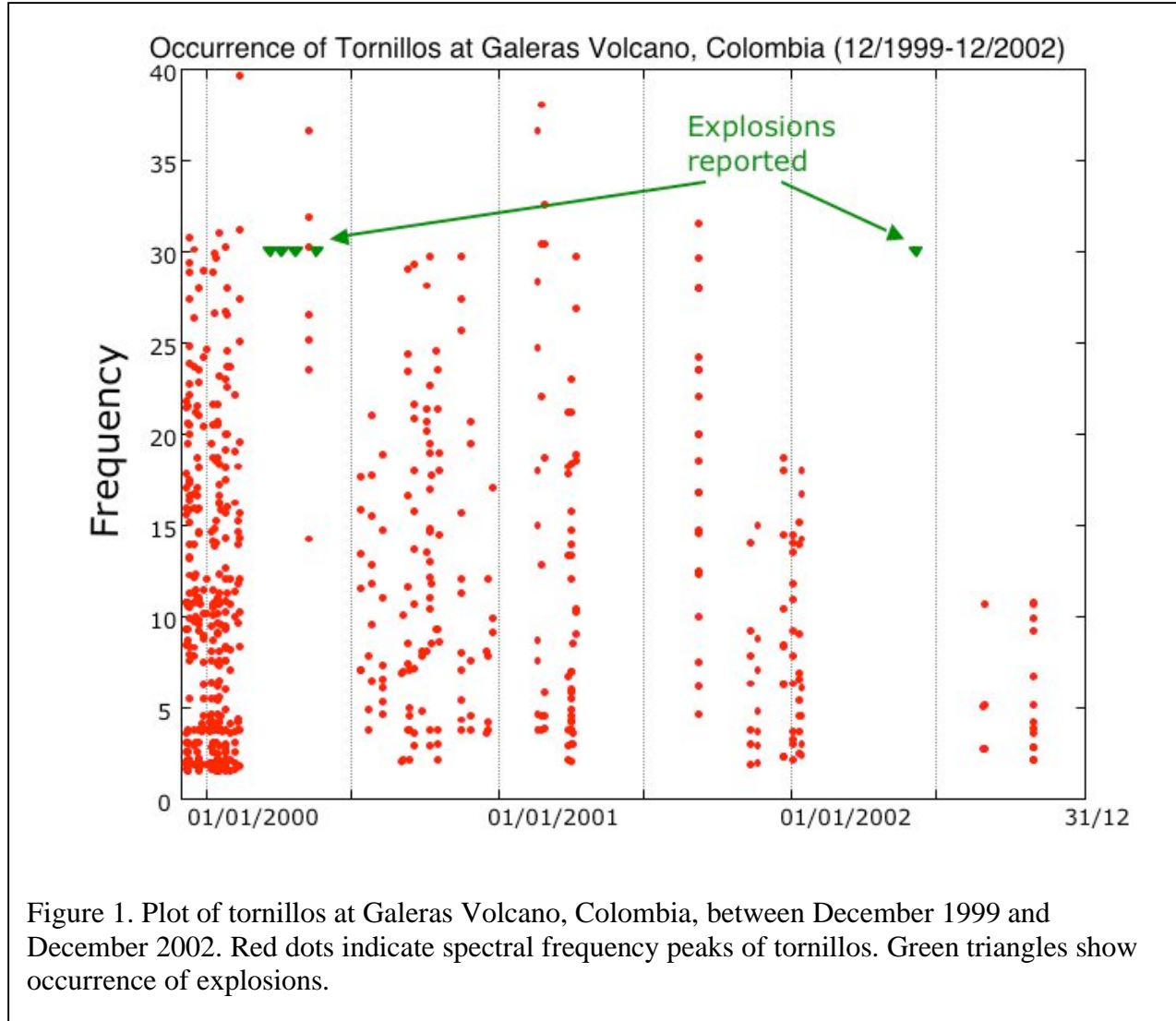
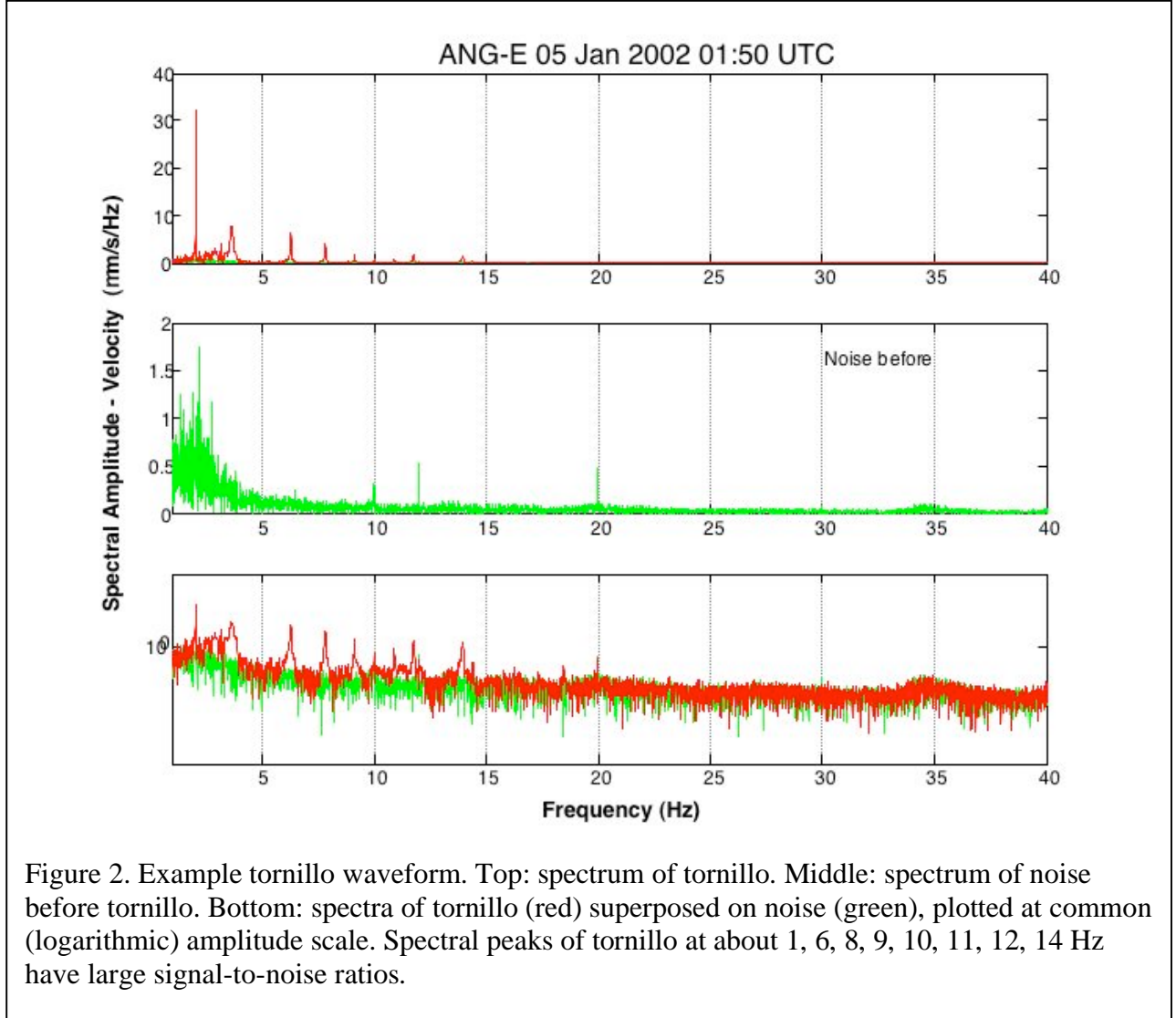


Figure 1. Plot of tornillos at Galeras Volcano, Colombia, between December 1999 and December 2002. Red dots indicate spectral frequency peaks of tornillos. Green triangles show occurrence of explosions.

range, tornillos are emergent and immediately display their characteristic, narrowband waveform. In contrast, the tornillos we have analyzed start with a very small amplitude, but clearly recognizable P-onset, followed about 0.25 s later by the arrival of wave energy on the horizontal traces, probably S-waves. This arrival becomes a complex wavepacket lasting between two and three seconds, before the long-lasting coda develops. Preliminary comparisons of the intermediate wavepackets for many different tornillos suggest two things: that they can be classified into families, and that these families are only indirectly related to the exact frequency or family of frequencies present in the coda. In our analysis, we investigate the three parts of the tornillo separately, before synthesizing the results to determine their source.

For each spectral peak in each tornillo, we bandpass filtered the three-component broadband seismograms to extract the signal for that peak and determined the main axis coordinate system X_1 -

X_2 - X_3 using the eigenvectors and eigenvalues of the covariance matrix of the Z-N-E seismograms (Matsumura, 1981, Kanasewich 1981, Seidl and Hellweg, 1991, Hellweg, 2000a). From the eigenvectors and eigenvalues we determined the kinematic parameters: azimuth Az_n , inclination In_n and rectilinearity Re_n . We then transformed the seismograms from the Z-N-E coordinate system of the seismometer into the X_1 - X_2 - X_3 coordinate system to make measurements in the time and



frequency domains. In the frequency domain, we determined the frequency of the peak's maximum f_{Pn} and its amplitude A_{Pn} , while we measured maximum velocity amplitude v_n , damping factor Q_n and the signal energy E_{Rn} in the time domain. For the characteristic coda of the tornillos, it is clear that the frequencies of the spectral peaks present, which may range from 1 Hz to 40 Hz, are related to the source, but we have not yet found a pattern allowing us to predict precisely which frequencies or families of frequencies will be present in any particular tornillo. For spectral peaks below 5 Hz, the polarization both remains constant during an individual tornillo and varies little from one tornillo to the next. This indicates that tornillos are all generated within a limited volume of the volcanic edifice. The variation in the polarization at higher frequencies should allow us to constrain the size of this volume (Hellweg, 2003).

M. Hellweg visited Los Alamos for 3 weeks in June where she presented initial results at a seminar. Together with L. House, she worked on characterizing the tornillo onset, as a first step in developing and testing models for the source of tornillos. When plotted as ground displacement, tornillo onsets, as recorded at ANG, can be segregated into two classes, those with positive and those with negative initial sign. These classes can be further divided into families depending on the frequency content of the initial pulse. In several of these families, there are clear differences in the onsets of tornillos which occurred before March 20, 2000 (date of a small explosion), and those between June, 2000, and June, 2002 (next small explosion). In view of these observations, we have begun to select and analyse data from the second crater rim station, ACH, to determine if the same classes and families can be recognized. We have almost completed a manuscript describing this work.

Although no tornillos had been recorded at Galeras Volcano since the end of 2002, the volcano began erupting again in mid-July, 2004. M. Hellweg visited the observatory (OVP) there in late August, bringing back digital data spanning the activity transition and eruption sequences until the end of her stay. In addition to the seismic stations, both the fumarole gas and electromagnetic stations were working, until their solar panels were covered by ash in late July. She discussed the activity transition with OVP colleagues, and collected recordings from past tornillos from 1997 – 1999, and from the station ACH. During the new eruption, tornillos were finally observed in the first week of September, 2004.

New Challenges or complications in meeting project objectives

No new challenges or complications were encountered in meeting project objectives.

Publications:

Hellweg, M. and L. House (2004): A warning bell? Tornillo events at Galeras Volcano, Colombia. Manuscript in preparation; to be submitted Geophysical Research Letters or Journal of Volcanological and Geothermal Research.

Presentations:

Presentations at Professional Meetings and Workshops:

Hellweg, M. and D. Seidl (2003): A warning bell? Tornillo events at Galeras Volcano, Colombia.

Eos Trans. AGU, 84(46), Fall Meet. Suppl., Abstract V52B-0436.

Hellweg, M. (2004): A warning bell? Tornillo events at Galeras Volcano, Colombia. Presented at the Workshop on Statistics in Volcanology, University of Bristol, Mar 22-26, 2004.

Hellweg, M., D. Dreger, and L. House (2004): Getting at the source: Tornillos at Galeras Volcano, Colombia. *Seismol. Res. Let.*, 74(2), 279.

Hellweg, M. (2004): Tornillo signals from Galeras Volcano, Colombia. I Congreso Latinoamericano de Sismología (Armenia, Colombia, 16-21 August, 2004).

Hellweg, M. (2004): One more time: Tornillos from the beginning. Annual Workshop of the Working Group “Seismic phenomena associated with volcanic activity” of the European Seismological Commission (La Palma, Spain, September 7 – 11, 2004).

Gómez, D., M. Hellweg, B. Buttkus, F. Böker, M.L. Calvache, G. Cortés, E. Faber, F. Gil Cruz, S. Greinwald, C. Laverde, L. Narváez, A. Ortega, H. Rademacher, G. Sandmann, D. Seidl, B. Silva, R.

Torres (2004): A volcano reawakens: Multiparameter observations of activity transition at Galeras Volcano (Colombia). Annual Workshop of the Working Group “Seismic phenomena associated with

volcanic activity” of the European Seismological Commission (La Palma, Spain, September 7 – 11, 2004).

Informal Presentations:

2004 Jan 13, “A warning bell? Tornillo events at Galeras Volcano Colombia”, *USGS Volcano Hazards Seminar*

2004 Jun 05, “A warning bell? Tornillo events at Galeras Volcano Colombia”, *Los Alamos National Laboratory*.

2004 Aug 27, “Tornillo signals from Galeras Volcano” *Universidad de Nariño, Pasto, Colombia*.

2004 Sep20, “A volcano reawakens: Multiparameter observations of activity transition at Galeras Volcano (Colombia)”, *Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, Germany*.

Name of the grad student and/or postdoc

Margaret Hellweg, Post-Doc, University of California, Berkeley

Visits to LANL and the University

Post-Doc Margaret Hellweg visited Los Alamos for 3 weeks in June during which she presented initial results at a Frontiers of Geosciences seminar .

Laboratory P.I. Leigh House had planned to visit U.C. Berkeley in early September, but was unable to do that because of obligations related to the Laboratory’s shutown. He now plans to visit U.C. Berkeley in early calendar year 2005.

LANL facilities used

Data storage and data analysis facilities were used for the analysis part of this work.

Budget Details

Budgets followed the details in the project’s renewal proposal.

Efforts to secure further funding from other agencies

This project concentrates on models for the source of the seismic events. A proposal has been submitted to the National Science Foundation, to examine the effects of realistic models for the volcanic edifice, including three-dimensional heterogeneity and complex topography, on the wavefield from various possible classes of seismic sources. Results, from the current project, both in terms of possible source models and wavefield parameters, will be a valuable foundation for the new project.